UDC 338.48:004.8

THE USE OF ARTIFICIAL INTELLIGENCE IN THE ORGANIZATION OF TOURIST ROUTES ON THE EXAMPLE OF ENOTOURISM

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Abstract

The article examines the theoretical and applied aspects of the use of artificial intelligence technologies in the formation and optimization of tourist routes in the field of enotourism under the conditions of the digital transformation of the industry. The relevance of the study is determined by the growing demand for personalized tourist products, the development of the smart tourism concept, and the necessity of introducing intelligent mechanisms for managing tourist flows in the cultural and gastronomic segment.

The purpose of the study is to identify the possibilities, advantages, and practical effects of applying artificial intelligence in the organization of enotourism routes, as well as to conduct their empirical assessment using international examples. The methodological basis includes methods of systems analysis, clustering, correlation analysis, machine learning algorithms, hybrid recommender systems, route optimization methods, and big data processing tools. The empirical base comprises information on more than 4,000 enotourism sites in Italy, France, Portugal, the United States, Russia and Georgia.

The role of artificial intelligence as a key element of the digital ecosystem of enotourism is demonstrated. The developed multi-level model of intelligent routing ensures the transition from static routes to adaptive personalized trajectories that take into account tourists' preferences, seasonality, and logistical constraints.

Empirical results revealed a strong positive correlation between the level of digitalization of destinations and tourist satisfaction with AI-generated routes, as well as a relationship between the reduction of planning time and the increase in the profitability of wineries. A comparison with traditional and agency-based routes confirmed the advantages of AI in terms of personalization, optimality, cultural richness and economic efficiency.

Keywords: artificial intelligence, enotourism, tourist routes, personalization, smart tourism, digitalization of tourism, Big Data, AR/VR technologies, Internet of Things (IoT), recommender systems, sustainable territorial development.

ИСПОЛЬЗОВАНИЕ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА В ОРГАНИЗАЦИИ ТУРИСТИЧЕСКИХ МАРШРУТОВ НА ПРИМЕРЕ ЭНОТУРИЗМА

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Реферат

В статье рассматриваются теоретические и прикладные аспекты применения технологий искусственного интеллекта при формировании и оптимизации туристских маршрутов в сфере энотуризма в условиях цифровой трансформации индустрии. Актуальность исследования определяется ростом спроса на персонализированные туристские продукты, развитием концепции smart tourism и необходимостью внедрения интеллектуальных механизмов управления туристскими потоками в культурно-гастрономическом сегменте.

Цель работы заключается в выявлении возможностей, преимуществ и практических эффектов применения искусственного интеллекта при организации энотуристических маршрутов и в проведении их эмпирической оценки на международных примерах. Методологическую основу составили методы системного анализа, кластеризации, корреляционного анализа, алгоритмы машинного обучения, гибридные рекомендательные системы, методы оптимизации маршрутов и инструменты обработки больших данных. Эмпирическая база включает сведения о более чем 4000 объектах энотуризма в Италии, Франции, Португалии, США, России и Грузии.

Показана роль искусственного интеллекта как ключевого элемента цифровой экосистемы энотуризма. Разработанная многоуровневая модель интеллектуальной маршрутизации обеспечивает переход от статичных маршрутов к адаптивным персонализированным траекториям с учетом предпочтений туристов, сезонности и логистических ограничений.

Эмпирические результаты выявили высокую положительную корреляцию между уровнем цифровизации дестинаций и удовлетворенностью туристов ИИ-маршрутами, а также связь между сокращением времени планирования и ростом доходности винодельческих хозяйств. Сравнение с традиционными и агентскими маршрутами подтвердило преимущества ИИ по персонализации, оптимальности, культурной насыщенности и экономической эффективности.

Ключевые слова: искусственный интеллект, энотуризм, туристские маршруты, персонализация, умный туризм (smart tourism), цифровизация туризма, большие данные (Big Data), технологии AR/VR, интернет вещей (IoT), рекомендательные системы, устойчивое развитие территорий.

Introduction

Wine tourism (enotourism) has in recent years become one of the most dynamically developing areas of cultural and gastronomic tourism, integrating tasting experiences, regional identity, and principles of sustainable territorial development. According to UNWTO data, the share of tourists choosing trips with a pronounced wine-gastronomic component exceeds 25 % in the structure of international travel and demonstrates a stable positive trend [1]. The growing interest in enotourism is accompanied by increasing demand for personalized routes and digital services that make it possible to enhance the quality of the tourist experience and to optimize the management of tourist flows at the destination level [2, 3].

In the context of the rapid digitalization of the tourism industry, the requirements for the implementation of intelligent technologies–ensuring deep analysis of tourist preferences, demand forecasting, and real-time route adaptation–are increasing. In this regard, artificial intelligence (AI) becomes a key element of the smart tourism concept, shaping new approaches to the design and management of tourist trajectories [4–6]. This determines the relevance of the present study, aimed at a systematic examination of AI capabilities in the formation and optimization of enotourism routes [7–9].

The purpose of the study is to identify the possibilities, advantages, and outcomes of applying artificial intelligence technologies in the organization and optimization of tourist routes in the field of enotourism, as well as to conduct their model-empirical assessment using examples of countries with different levels of digital maturity.

To achieve this goal, the study addresses the following tasks:

- to analyze modern AI technologies used in tourism;
- to determine the characteristics of enotourism as an object of intelligent routing;
- to assess the effectiveness of AI for personalization and optimization of tourist routes;
- to develop and test an intelligent routing model using the example of six countries with different levels of digital maturity.

The object of the study comprises the processes of organizing and personalizing tourist routes in enotourism. The subject of the study is artificial intelligence technologies applied in the formation and optimization of enotourism routes.

The scientific novelty lies in the development of a comprehensive model for applying AI to the construction of enotourism routes based on machine learning algorithms, clustering, and big data analysis [10–12]. The model was tested using the examples of Italy, France, Portugal, the United States, Russia and Georgia.

Intelligent Technologies in the Formation and Optimization of Enotourism Routes

Contemporary research in the field of enotourism underscores its interdisciplinary character, integrating aspects of cultural studies, marketing, geography, and the digital economy. Enotourism is regarded not only as a form of specialized leisure but also as an important instrument of territorial branding that contributes to the preservation of cultural heritage, the development of rural territories, and the formation of sustainable tourist clusters [3, 7, 8].

The development of enotourism in recent decades is directly associated with the digitalization of the tourism industry. Geographic information systems, online booking, recommendation services, mobile applications, and big data analytics form the foundation for the transition from standard routes to intelligently managed, adaptive tourist trajectories [13–15]. The use of artificial intelligence technologies reinforces this process: AI enables the creation of dynamic routes that take into account seasonality, site congestion, tourist preferences, and logistical constraints. Since the creation of such adaptive routes requires precise analysis of user characteristics and the identification of hidden patterns within large data sets, personalization tools acquire particular significance. The scientific literature emphasizes the role of hybrid recommendation systems and clustering algorithms as key mechanisms for shaping individualized tourist experiences [6, 16, 18].

At the same time, the practical implementation of digital and intelligent technologies in enotourism varies considerably across countries, as their effectiveness is determined by the level of digital maturity of tourism ecosystems. Research shows that the pace of digitalization depends not only on technological infrastructure but also on cultural characteristics of tourist experience perception, institutional environments, and the degree of development of regional clusters [7, 9, 16, 19]. These factors define the unequal readiness of countries to integrate intelligent technologies and predetermine differences in the expected effects of their application. In this regard, comparing the digital maturity level of countries with the characteristics of their wine tourism makes it possible to identify regional contexts in which the implementation of AI has the greatest potential.

As comparative analysis demonstrates, the development of digital infrastructure and the breadth of digital platform usage directly determine the possibilities for integrating intelligent technologies and the extent of their influence on the quality of the wine experience (Table 1) [3, 9, 10, 12].

Table 1 – Comparison of Digital Maturity and Readiness for AI Implementation in Enotourism by Country

Country	Main Sources and Digital Platforms	Level of Digitalization, %	Readiness for AI Implementation	Features of the Digital Ecosystem
Italy	Enoteca Italiana, WineTourism.com, regional registries, Italian Wine Lover, Eataly	88	High	Advanced recommendation systems and integration of smart tourism (Tuscany, Piedmont)
France	OpenWineData, TripAdvisor, Google Places, state wine registries	90	Very high	State-supported digitalization, AI in destination management (Bordeaux, Burgundy)
Portugal	Turismo de Portugal DataHub, WineTourism.com	82	High	Development of national AI platforms and integration of regional data
USA	Yelp, Google, OpenStreetMap, Napa Big Data Initiative	92	Maximum	Full integration of Big Data and AI, leading investor in automation
Russia	VisitKuban, regional registries, Google Maps	62	Medium	Partial digitalization, pilot AI projects in Krasnodar Krai
Georgia	Georgia.travel, wine associations, OpenStreetMap	58	Low–medium	Early stage of digitalization, high growth potential in Kakheti

Note – Source: Compiled by the author based on data from OECD, WEF, the World Bank and national tourism platforms [3, 8–10, 12, 20, 24–29].

Interpretation of the presented data makes it possible to identify differences among national models of enotourism. In countries with a well-developed wine tourism culture – Italy, France, the United States and Portugal – a high level of digitalization ensures the widespread application of AI for creating emotionally rich, personalized routes and interactive services [8, 9, 21, 22–26]. In regions where wine tourism retains a predominantly traditional or event-driven character (Russia, Georgia), digital infrastructure remains limited, which results in the use of AI primarily for navigational and informational purposes [27–29].

Against the background of the identified differences, it becomes evident that the potential for introducing intelligent technologies into enotourism is determined by a combination of national and regional conditions. This necessitates a shift from macro-level analysis of digitalization to the examination of specific areas of AI application within the sector. A key domain in which AI possesses the most significant practical potential is the organization of tourist routes. The main possibilities for applying AI in the construction of wine routes may be conventionally grouped into five categories:

1. Personalization. Personalization of routes in enotourism is based on machine learning methods, recommendation systems, and predictive analytics, which make it possible to account for multidimensional data about tourists: taste preferences (wine varieties and styles, price categories), socio-demographic characteristics, travel and booking history, geolocation trajectories, digital traces on tourism platforms, textual reviews, and sentiment analysis results [9, 13, 16, 30]. The use of these technologies enables the formation of a detailed tourist profile and the construction of routes that most accurately correspond to individually defined interests.

https://doi.org/10.36773/1818-1112-2025-138-3-185-192

The transition from static to dynamic adaptive routes is a direct consequence of AI implementation: the system becomes capable of adjusting the route in real time. When weather conditions, winery congestion, transportation situations, or the tourist's current preferences change, the algorithm automatically proposes alternative sites to visit, modifies the sequence of tastings, or supplements the route with cultural and gastronomic activities [15, 17, 28], thereby enhancing route flexibility and the overall quality of the travel experience.

The functional advantages of personalized routes create prerequisites for economic effects. Personalization contributes to increased booking conversion, longer trip duration, and higher average spending due to more accurate alignment of the tourism product with consumer expectations [7, 9]. For wine-producing regions, this entails a more even distribution of tourist flows, reduced pressure on the most visited sites, and broader involvement of small wineries in the tourism economy [13, 15, 18].

In addition to economic outcomes, personalization has a significant impact on the sustainable development of territories. Individualized routes make it possible to consider environmental constraints, the carrying capacity of sites, and the seasonal differentiation of tourist flows, thereby forming mechanisms for balanced management of enotourism destination development [9, 15, 18, 22].

2. AR/VR Technologies. The introduction of augmented reality (AR) and virtual reality (VR) technologies forms a new format of tourist–territory interaction based on the effect of digital immersion. Immersive solutions make it possible to model tasting spaces, wine cellars, vineyards, and technological processes in a 360° format, expanding the accessibility of routes and enhancing the emotional richness of the travel experience [19, 20].

VR technologies are used primarily for preliminary and remote tours, providing virtual tourists with the opportunity to become acquainted with the architecture of wineries, their history, and tasting programs. This approach serves as an effective motivational tool and increases the likelihood of an eventual in-person visit [9, 20, 22].

The expansion of AR/VR functionality at the stage of direct route visitation necessitates consideration of the role of augmented reality. AR technologies are used directly along the route and provide superimposition of digital content onto physical space, visualizing parameters of the terroir, grape varieties, climatic characteristics, and elements of the winemaking cycle [19, 20]. Their integration with AI allows the depth and format of visual accompaniment to be adapted to the tourist's interests–educational, gastronomic, cultural, or architectural [16, 18, 20].

International practice demonstrates that AR/VR solutions perform not only entertainment functions but also serve as tools of territorial marketing, digital branding, and preservation of the cultural heritage of wine-producing regions [9, 22, 29], strengthening their positioning within the global tourism space. A more detailed examination of cross-country differences shows that the highest maturity of AR/VR technologies is observed in Italy, France, and the United States, where they are integrated into smart tourism strategies, whereas in Portugal, Russia, and Georgia their dissemination is predominantly limited to pilot initiatives [9, 17, 22].

Overall, AR/VR technologies simultaneously provide preliminary familiarization with routes and create an immersive tourist experience that enhances the emotional perception of the territory and its competitiveness in the digital economy [9, 20, 22].

3. Big Data constitutes a key element of intelligent management in enotourism routes, ensuring the transition from static planning to dynamically adaptable tourist trajectories [1, 13, 15, 17]. The analytical framework of such systems is formed on the basis of data on tourist movements, bookings, transactions, user digital traces, climatic conditions, infrastructural characteristics, and seasonal activity of territories [15, 30, 34]. Integration of these heterogeneous sources enables the construction of multidimensional models of tourist behavior and significantly increases the accuracy of demand forecasting [7, 15, 17].

Machine learning provides the possibility of anticipatory management of tourist flows: routes are adjusted not only in response to emerging congestion but also on the basis of probabilistic scenarios of its occurrence [13, 15, 17], which is especially important for regions with pronounced seasonality and limited carrying capacity [1, 9, 13, 15].

In addition to temporal parameters, Big Data exerts a substantial influence on the spatial organization of routes. Its use makes it possible to identify zones of tourist concentration, construct logistically rational sequences of visits, and differentiate routes by traveler type [13, 15, 30], which leads to reduced travel time and shorter queues [7, 9].

In the context of sustainable development, Big Data performs the function of balancing tourist load by redistributing flows between primary and peripheral sites and stimulating the involvement of small wineries in the region's tourism ecosystem [1, 9, 15]. Economic effects include increased accuracy of recommendations, longer average tour duration, higher rates of repeat visits, and substantial growth in digital bookings [1, 15, 30], as well as improved effectiveness of marketing campaigns through more precise targeting [7, 9, 17].

Thus, Big Data serves as the foundation for the formation of intelligent tourism ecosystems in which routes, events, tasting programs, and logistical processes are integrated into a unified digital environment for managing the tourist experience [1, 9, 15, 17, 30].

4. Multisensory Technologies. Multisensory technologies emerge at the intersection of digital solutions, cognitive psychology, and the experience economy. They activate visual, auditory, olfactory, and tactile perceptual channels, enhancing emotional engagement, improving route memorability, and forming stable associations with the territory and the wine product [9, 33].

In enotourism destinations, multisensory approaches are implemented through immersive tastings, interactive wine museums, audiovisual installations, and aroma stations that link the perception of wine with the context of terroir, climate, technologies, and cultural traditions [9, 19, 34]. The combination of visual effects, spatial sound, and olfactory stimuli increases the subjective evaluation of tasting quality and stimulates repeat visits [9, 33]. Integration of AI enables the personalization of sensory scenarios–the adaptation of lighting, sound, and aromatic parameters to the tourist's individual profile [9, 16, 18].

In practice, multisensory technologies are also used for spatial structuring of routes: they make it possible to differentiate tasting rooms, educational zones, and cellars, creating a coherent sensory trajectory of the journey. The highest levels of maturity of such technologies are observed in Italy, France, and the United States, where they are integrated into strategies for forming an immersive tourist experience [9, 33], whereas in Portugal, Russia, and Georgia their dissemination remains more limited [23–29, 33].

In combination with AR/VR, multisensory formats enhance the educational and cultural potential of routes, create unique digital assets of territories, and increase their attractiveness [9, 18, 33], while the use of AI enables the identification of the most effective sensory scenarios and improves the economic performance of enotourism projects [9, 18, 33].

5. Integration with Internet of Things (IoT) Technology. The Internet of Things (IoT) forms the technological foundation of "smart" enotourism routes, linking the physical infrastructure of wine-producing regions with digital management platforms [12, 14, 17, 36]. Sensor networks–traffic counters, microclimate sensors, RFID tags, beacons, and load-monitoring systems–ensure continuous real-time data flow.

In this context, within advanced digital ecosystems, IoT is applied not only in the tourism sector but also in winemaking, connecting the processes of "vineyard–winery–route" [17, 37, 38] and enhancing the sustainability and synchronization of service delivery.

Unlike Big Data, which operates primarily at the strategic level, IoT provides route adaptation at the operational level by responding to weather changes, queues, traffic congestion, and mass tourist arrivals [13, 15, 36]. Integration of IoT with mobile applications makes it possible to automatically adjust routes, suggest alternative locations, regulate tasting schedules, and reduce the risk of site overload [12, 14, 17]. Such operational flexibility directly translates into economic advantages, including reduced operating costs, increased throughput without infrastructure expansion, improved planning accuracy, and growth in digital bookings [9, 14, 36].

Given the outlined functional and economic effects of IoT, the degree to which different countries possess the conditions for its practical implementation becomes an important issue–one determined by the level of digital maturity of their tourism ecosystems. The highest level of IoT maturity is observed in Italy, France, and the United States, whereas in Portugal, Russia, and Georgia the development of this technology remains at an emergent stage [28, 23–26, 28, 29].

Overall, IoT is viewed as a key element of the technological transformation of enotourism, ensuring the transition from static routes to adaptive digital ecosystems that account for context, behavior, and the dynamics of tourist flows in real time [9, 12, 14, 217, 36].

Summarizing the examined directions of digital transformation, it may be noted that the combined integration of artificial intelligence technologies, AR/VR, Big Data, multisensory solutions, and IoT forms a qualitatively new model for organizing enotourism routes. This model makes it possible to move from fragmented logistical and excursion practices to a unified intelligent system for managing the tourist experience, oriented toward sustainable territorial development, improved service quality, and enhanced competitiveness of wine-producing regions.

Building on the results of synthesizing theoretical and applied approaches to the use of artificial intelligence in enotourism, as well as on the analysis of the corresponding digital technologies [1, 9, 12–15, 17, 30, 37], a multi-level model for organizing enotourism routes was developed. This model is aimed at forming personalized tourist trajectories optimized with regard to traveler preferences, time constraints, seasonality, and geographic accessibility of sites. The structure of the model includes three interconnected levels integrated into a unified system of intelligent route planning (Figure 1).

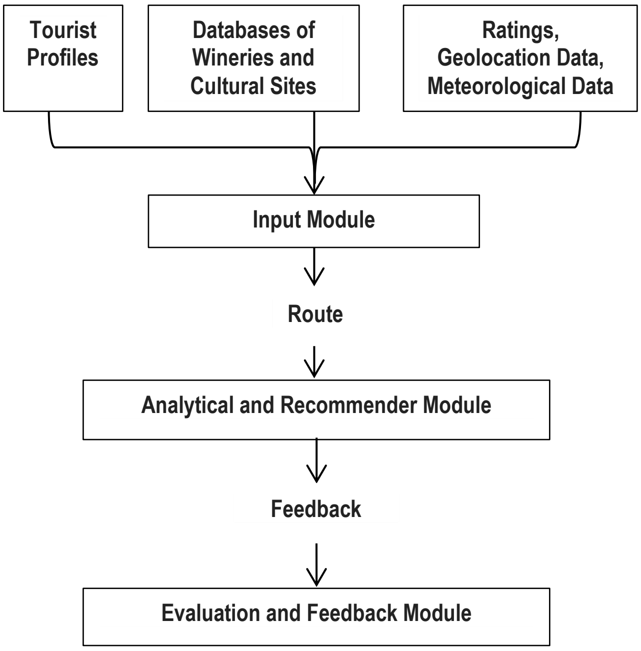

Figure 1 – Model of Enotourism Route Organization Using Artificial Intelligence

Note – Source: Author's own development based on the concept of smart tourism destinations and digital tourism ecosystems [2, 5, 14, 15, 16, 38].

Transitioning to the description of the functional structure, it should be noted that the first level–the data acquisition module–aggregates information from open sources and API platforms (WineTourism.com, OpenStreetMap, Google Places, TripAdvisor, national registries) [1, 9, 30, 35]. The system receives data on tourists, wineries, schedules, reviews, geolocation, and seasonal constraints. Normalization procedures ensure their comparability and prepare them for subsequent analytical processing.

The second level – the analytical and recommendation module–performs user segmentation based on clustering methods (k-means, DBSCAN) [13, 18, 30] and generates routes using hybrid recommendation algorithms [6, 16]. When generating a route, the system accounts for the relevance of sites to the tourist's interests, transport accessibility, ratings, seasonality, and the event load of the territory. Logistical optimization is carried out using Dijkstra and A* algorithms [15].

The third level–the evaluation and feedback module–collects user assessments, survey results, sentiment analysis of reviews, and data on repeat visits [9, 18, 30]. These inputs are applied for model retraining, refinement of personalization parameters, and improvement of recommendation accuracy.

Taken together, the proposed model ensures real-time route formation, logistics optimization, consideration of seasonal and infrastructural constraints, enhanced safety of tasting tourism, balancing of tourist flows, and increased efficiency of enotourism facilities. Thus, the model functions as a universal intelligent platform supporting the sustainable development of wine-producing territories and the integration of enotourism into the digital ecosystem of smart tourism.

To assess the practical applicability of the proposed model, it was tested using the example of six countries: Italy, France, Portugal, the United States, Russia, and Georgia. The selection of destinations is determined by their significant contribution to the global wine tourism market, as well as by pronounced differences in the digitalization of tourism infrastructure and the extent of AI technology adoption [1, 3, 10, 11, 17].

Routes were generated on the basis of a universal meta-request from a tourist, including preferred trip duration, a combination of popular and authentic sites, temporal and logistical constraints, seasonal parameters, winery load levels, and the need to incorporate tasting, cultural, and natural activities. This approach ensures comparability of results across countries and reflects the typical logic of user interaction with an AI system [12, 16, 18].

He approbation of the model consisted of three interconnected stages.

At the first stage, the interpretation of the user request was carried out, and a tourist profile was generated on the basis of aggregated data on preferences, digital traces, route history, and cultural orientations.

At the second stage, intelligent filtering of enotourism sites was performed using data from OpenWineData, WineTourism.com, TripAdvisor API, OpenStreetMap, Google Places, and national tourism registries [1, 9, 30, 35], taking into account opening hours, accessibility, congestion levels, climatic, and seasonal factors.

At the third stage, the route was generated using hybrid recommendation algorithms and optimized with A* and Dijkstra methods, which made it possible to minimize temporal and transportation costs [15].

The results are presented in Table 2, which contains a list of wineries, route duration, the digital tools employed, and the key effects of AI implementation.

Analysis of the data in the table shows that AI-generated routes in all six countries combine major historical wineries with small family-owned estates. Such a combination expands the cultural richness of the journey and supports a more even distribution of tourist flows. In Tuscany, the three-day circular route reduced planning time by 38 % and yielded an ROI of approximately 23 %. In Burgundy, the application of Big Data and digital wine maps enabled high personalization accuracy (precision = 0,91), whereas in Napa Valley the highest level of automation in traffic and sales forecasting was recorded [9, 13, 16, 17, 37].

In Portugal, routes were optimized according to climatic and seasonal parameters, resulting in a 17 % increase in visitation and a 20 % rise in average tourist spending. In Russia, the VisitKuban AI Route model and IoT sensors increased booking conversion by 21 %. In Georgia, routes became more content-rich and extended tour duration by 18 %, taking into account cultural events in the region [25, 27–29, 31].

The obtained results confirm that the effectiveness of intelligent routing directly depends on the quality of the initial data: completeness, relevance, and coherence of geolocation, rating, temporal, and event parameters. In countries with a developed digital infrastructure, the models demonstrate high adaptability and accuracy, whereas fragmentation or limited availability of data in regions with lower levels of digitalization reduces calculation effectiveness and restricts the scale of AI implementation [10, 11, 17, 30].

To quantitatively confirm the relationship between the level of digitalization of tourist destinations and tourist satisfaction with AI-generated routes, a Pearson correlation analysis was conducted. The analysis was based on a sample of six countries ($n = 6$) differing in digital maturity. As an indicator of digital maturity, the composite Digital Maturity Index (DMI) was used, based on DESI, the World Economic Forum's Digital Development Index, and World Bank data [3, 10, 11, 17]. Tourist satisfaction was assessed using the Tourist Satisfaction Index (TSI), formed from user ratings, sentiment analysis of reviews, and online surveys ($n = 300$) [9, 10, 18].

The results presented in Figure 2 indicate a strong positive correlation between the digital maturity index (DMI) and the level of tourist satisfaction with AI-generated routes ($r = 0{,}92$; $p < 0{,}05$). A moderate positive relationship was also identified between the reduction in route planning time and the increase in profitability of wineries ($r = 0{,}71$), which confirms the economic efficiency of intelligent routing [16, 17, 37].

Table 2 – Routes Generated by AI for Various Enotourism Regions

Country / Region	Key Sites (Wineries)	Route Duration, Days	Digital and Intelligent Elements of the Route	Features of the AI-Generated Route
Italy / Tuscany	Antinori, Castello di Ama, Castello di Brolio, Castello Banfi, Caparzo, Avignonesi	3	Hybrid recommendation system; A* and Dijkstra algorithms; integration with IoT monitoring and AR/VR	Circular route; logistical optimization; 38 % reduction in planning time; ROI ≈ 23 %
France / Burgundy	Château de Pommard, Domaine Roulot, Maison Chanson, Gevrey-Chambertin, Château de Chamirey	**3**	Big Data and review analysis; predictive modeling of visitation; digital tastings	High personalization accuracy (precision = 0,91); integration with the digital wine map system
Portugal / Douro Valley	Quinta da Pacheca, Quinta do Seixo, Quinta do Bomfim, Quinta da Roêda	4	Tourist clustering; adaptive routing based on weather data; NLP-based review analysis	Seasonality and climate optimization; 17 % increase in visitation; 20 % increase in average tourist spending
USA / Napa Valley	Robert Mondavi Winery, Stag's Leap Wine Cellars, Beringer Vineyards, Castello di Amorosa, Artesa Vineyards & Winery	3	Machine learning for demand forecasting; integration with IoT and VR tours	High level of automation; traffic and sales forecasting; ROI ≈ 26 %
Russia / Krasnodar Krai	Abrau-Durso, Fanagoria, Chateau de Talu, Guy-Kodzor, Kuban-Vino, Lefkadia	3	VisitKuban AI Route platform; IoT sensor integration; booking API and geoanalytics	21 % increase in booking conversion; use of Big Data for flow analysis
Georgia / Kakheti	Shumi Winery, Tsinandali Estate, Kindzmarauli Corporation, Khareba Winery	2–3	SmartWineGeorgia system; hybrid recommendation algorithms; IoT integration	18 % increase in tour duration; formation of "smart" routes considering cultural events

Note – Source: compiled by the author based on [1, 3, 9, 10, 13, 14, 16–18, 29, 30].

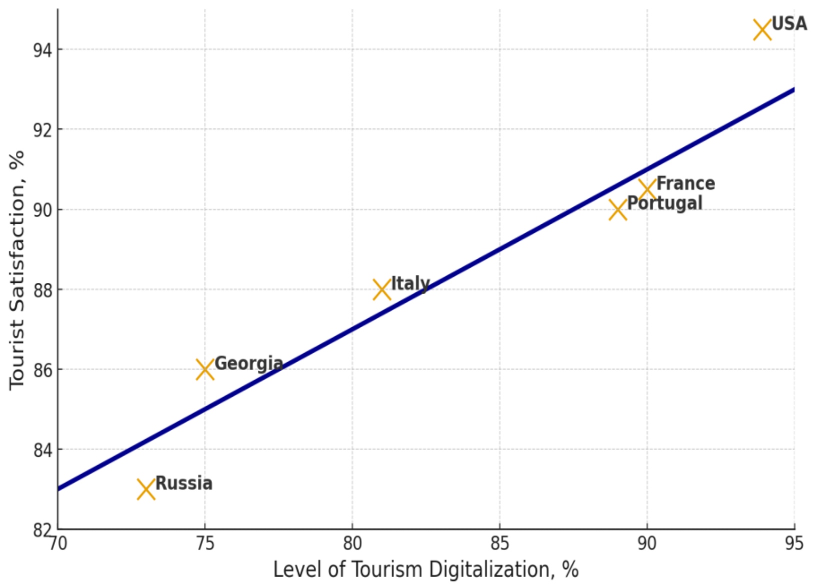

Figure 2 – Correlation Dependence between the Level of Digital Maturity of Tourist Destinations (DMI) and the Tourist Satisfaction Index (TSI)

Note – Source: Author's own development based on aggregated data from UNWTO, OECD, the World Economic Forum, the World Bank, and user review platforms [1, 3, 10–12, 17, 30, 37].

According to the graph, a 10 % increase in the level of territorial digitalization correlates with an approximate 3,9 % rise in tourist satisfaction, indicating the significance of digital maturity as a factor in the competitiveness of enotourism destinations. At the same time, the obtained results should be regarded as indicative: the identified relationships reflect stable trends in the digital transformation of enotourism but do not permit strict causal interpretation. This underscores the need to expand the panel sample and conduct more advanced econometric analysis [1, 10, 16, 17].

As an illustrative example of the functioning of the developed AI model, a "Circular Route through Tuscan Wineries" was generated on the basis of a tourist meta-request that included a combination of well-known winery brands and small family estates, optimization of travel time, consideration of seasonality and site congestion, and integration of tasting, gastronomic, and cultural activities. The spatial configuration of the route is presented in Figure 3.

The route unites three key wine-producing zones of the region– Chianti Classico, Montalcino, and Montepulciano – which differ in terroir, grape varieties, technological practices, and historical-cultural context. The set of sites selected for visitation includes both major wineries (Antinori, Castello di Ama, Castello di Brolio, Banfi, Avignonesi) and small estates employing organic and biodynamic practices (Podere le Ripi, Salcheto), thereby ensuring diversification of the wine experience and deeper acquaintance with local traditions [35, 38].

The total length of the route is approximately 285 km, corresponding to a trip duration of 2–3 days. Logistical parameters were calculated using data from OpenStreetMap, the Google Maps Distance Matrix API, and Tuscany's regional road services, while information on wineries and infrastructure was sourced from WineTourism.com, the TripAdvisor API, and the Open Tourism Data Hub Toscana [1, 23, 35, 38]. Optimization of the order of visits was performed using A* and Dijkstra algorithms, which made it possible to minimize transportation costs while maintaining a rich program.

A detailed logistical profile of the route, including distances, travel time, and the functional characteristics of individual segments, is provided in Table 3.

Figure 3 – Scheme of the Circular Route through the Wineries of Tuscany

Note – Source: Author's own development based on data from regional digital tourism platforms of Tuscany, intelligent routing algorithms, and tourism aggregators [15, 23, 30, 35].

Analysis of the logistical parameters presented in Table 3 shows that transfers between sites typically take 15–40 minutes, ensuring a comfortable travel pace and reducing transportation-related fatigue for the tourist. The route is structured according to the principle of gradual immersion into the region's wine territories: from large technologically advanced wineries to intimate family estates, and subsequently to premium producers in the Brunello di Montalcino and Vino Nobile di Montepulciano zones. This configuration maintains the internal coherence of the route and provides a diverse wine experience. The longest transfer (65–75 minutes) occurs at the final stage – returning from Montepulciano to Florence. This is due to the geographical characteristics of the region and does not disrupt the overall travel balance thanks to the circular structure of the route.

A significant element in the design of the route was the integration of safe enotourism requirements into the process of intelligent routing, specifically excluding driving after tastings. Special safety time slots were embedded into the routing algorithm, mandating intermediate non-driving activities–gastronomic breaks, cultural stops, and walking segments–as well as recommendations for using alternative transportation. In cases where the tourist prefers individual car travel, the system automatically adjusts the tasting format ("non-driving tastings") or offers the use of transfers, wine road shuttles, or taxis, in accordance with international standards of sustainable and responsible wine tourism [12, 14, 17].

The circular configuration of the route, beginning and ending in Florence, ensures logistical coherence, eliminates duplication of segments, and contributes to an even distribution of tasting activities. Accounting for time constraints, visitation density, and distances between sites made it possible to construct an optimal sequence of winery visits and associated locations, preventing program overload and ensuring a comfortable travel experience.

The spatiotemporal structure of the enotourism route generated by artificial intelligence is characterized by a reduction in the share of logistical costs while maintaining a high level of thematic richness. According to the data in Table 3, the total travel time accounts for 26,8 % of the route's overall duration. The remaining 73,2 % is allocated to thematic components: tastings and production visits (46,2 %), cultural and historical site visits (23,1 %), and gastronomic activities (3,9 %). This proportion confirms the effectiveness of algorithmic optimization, which simultaneously minimizes logistical losses and expands the set of sites included in the route.

The example of the route through the wine-producing territories of Tuscany demonstrates that the application of artificial intelligence not only reduces planning time and rationalizes travel logistics but also promotes deeper integration of family-owned estates into the tourist flow, strengthens the cultural dimension of the route, and supports the principles of safe and sustainable enotourism. The totality of the obtained results confirms the practical viability of the intelligent routing model and its strong potential for replication in other wine-producing regions of the world.

To enhance the analytical substantiation of the study, a comparison was conducted between the AI-generated route through the wineries of Tuscany and the two most widespread models of organizing enotourism travel–the traditional self-planned route and the standard agency route. The comparative characteristics of these formats, presented in Table 4, make it possible to identify their fundamental differences in the degree of personalization, logistical efficiency, level of authenticity and compliance with the requirements of safe and sustainable enotourism.

Table 3 – Logistical Profile of the AI-Generated Route through Tuscan Wineries

Route Stage	Travel Segment	Distance, km	Travel Time, min	Key Characteristic of the Route and the Winery (at Destination)
1	Florence → Antinori nel Chianti Classico	30	30	Departure from the arrival point; Antinori is a large, technologically advanced winery with a well-developed enotourism infrastructure
2	Antinori → Castello di Ama	28	35	Transfer within the Chianti Classico cluster; Castello di Ama is an art-winery combining contemporary art with terroir-driven wines
3	Castello di Ama → Castello di Brolio	20	25	Historic Chianti area; Castello di Brolio is a castle-winery with a pronounced historical and cultural context
4	Castello di Brolio → Fattoria La Ripa	14	18	Transition to a more intimate location; Fattoria La Ripa is a family estate emphasizing local winemaking traditions
5	Fattoria La Ripa → Castello Banfi	32	40	Shift from Chianti to southern Tuscany; Castello Banfi is a major wine resort and enotourism center in the Brunello di Montalcino zone
6	Castello Banfi → Podere le Ripi (Montalcino)	20	25	Short transfer within the Brunello zone; Podere le Ripi is a boutique biodynamic winery
7	Podere le Ripi → Caparzo	10	15	Movement within the Montalcino DOCG; Caparzo is a traditional Brunello winery with a developed tasting infrastructure
8	Caparzo → Avignonesi (Montepulciano)	48	50	Transition from the Brunello zone to the Vino Nobile zone; Avignonesi is one of the key Montepulciano wineries oriented toward organic/biodynamic production
9	Avignonesi → Florence (route closure)	65	75	Return to the starting point; completion of the circular route with a logically structured transition from wine zones to the region's cultural capital

Note – Source: compiled by the author based on [23].

Table 4 – Comparative Characteristics of Traditional, Agency and AI-Generated Enotourism Routes through Tuscan Wineries

Indicator	Traditional Route (self-planned)	Agency Route (regional tour operators)	AI-Generated Mixed Route
Degree of personalization	Low – depends on the tourist's experience and random information selection	Moderate – adaptation possible within template programs	High – formed on the basis of the tourist's profile, preferences, logistical and cultural parameters
Consideration of opening hours, seasonality, site congestion	Weak	Partial	Full – automatic optimization of schedules, seasonal factors, and traffic
Diversity of wineries	Limited – mainly large, well-known estates	Limited – wineries adapted for tourism	Maximum – combination of major historical and family wineries (Podere le Ripi, Salcheto, etc.)
Authenticity of experience	Unstable	Moderate	Very high – integration of artisanal practices and local cultural points
Logistics (route optimality)	Low – chaotic movements, high transportation costs	Moderate – route constructed without personalized optimization	High – optimization based on A* and Dijkstra algorithms
Average planning time	3–5 hours	1–2 hours	Reduced by 38 % (≈ 18–25 minutes)
Average travel time between points	45–90 minutes	40–70 minutes	18–45 minutes
Consideration of tasting safety (driving safety)	Absent	Minimal	Full – "alcohol-sensitive time slots," transfers, non-driving tastings
Integration of cultural sites (Siena, Montepulciano, etc.)	Inconsistent	Partial	Structured – based on clustering and temporal constraints
Tourist satisfaction (survey n = 300 and sentiment analysis ≥ 0.78)	82–84 %	86–88 %	92–94 %
Recommendation accuracy (Precision@K)	–	–	0,87 – level of mature hybrid recommender systems
ROI of wineries (Return on Investment)	0–5 %	8–12 %	≈ 23 % due to increased tastings and higher average spending
Key performance indicators of the route (KPI)	Low – no analytics	Moderate	High – load balancing, logistics optimization, increase in average spending
Accessibility of digital services	Random	Moderate	Full – integration of WineTourism.com, OpenStreetMap, TripAdvisor

Note – Source: compiled by the author based on aggregated data from digital tourism platforms, regional statistics, and analytical studies in the field of smart tourism [1, 12, 13, 15, 16–18, 30, 37, 39].

The analysis shows that traditional routes, based on independent search and fragmented digital sources, are characterized by limited diversity of wineries, low personalization, and weak consideration of opening hours, seasonality, and site congestion. This results in increased time costs for planning (3–5 hours), chaotic movements, and reduced tourist satisfaction (82–84 %). Agency routes are more structured and predictable; however, they retain a high level of standardization and are oriented toward an averaged traveler profile. Their flexibility is constrained by template-based programs, which limits the diversity of visited sites and restricts satisfaction levels (86–88 %).

In contrast to these models, the AI-generated route is formed through the integration of the tourist's personal preferences, spatiotemporal parameters, seasonal factors, site load data, and user analytics. This ensures maximal variability of visited wineries–from major historical estates to small family producers–and significantly enhances the authenticity and depth of impressions. A substantial advantage of the AI-based approach lies in the full automation of accounting for opening hours, seasonal constraints, transport accessibility, and tourist traffic intensity–capabilities unavailable in traditional and agency formats.

The AI-generated route fundamentally differs from traditional and agency models of travel organization in its construction mechanism: it integrates data on tourist preferences, seasonality, logistics, site congestion, and user evaluations. Such an approach creates a maximally diverse and balanced set of wineries and enhances the authenticity of visits. Its key advantage is the automatic adjustment of temporal parameters and schedules, ensuring that the route meets the requirements of sustainable and responsible wine tourism.

The logistical efficiency of the AI-generated route is ensured through the application of A* and Dijkstra algorithms, which optimize distances and travel time. According to Table 4, average transfer time is reduced to 18–45 minutes (compared to 45–90 minutes for traditional routes and 40–70 minutes for agency routes), while planning time decreases by 38 %, averaging 18–25 minutes. An important distinction between the AI-generated route and traditional or agency formats is the full consideration of safe enotourism requirements: the system automatically generates safety time windows, adapts tasting formats, or proposes alternative transportation solutions, ensuring compliance with international standards of responsible wine tourism [12, 17, 36].

Comparative analysis of economic efficiency demonstrates the advantages of intelligent routing: winery ROI increases to 23 % due to growth in the number of tastings, higher average spending, and expansion of accompanying services, whereas in traditional routes this indicator is 0–5 % and in agency routes 8–12 %. The AI-generated route is characterized by the highest levels of tourist satisfaction (92–94 %) and recommendation accuracy, corresponding to the performance of mature hybrid recommender systems.

Taken together, the results of the analysis presented in Table 4 show that the AI-generated route provides not only quantitative advantages–reduced planning time, optimized logistics, and increased economic returns–but also a qualitatively different level of personalization, cultural richness, and safety. This confirms the high potential of intelligent routing systems in the development of wine-producing territories and the formation of sustainable digital tourism ecosystems [9, 14, 18, 38].

Conclusion

The conducted study has shown that artificial intelligence technologies, at the current stage of tourism industry development, are becoming key instruments for managing enotourism routes. The use of AI enables the transition from static and standardized travel models to adaptive, personalized trajectories that account for individual tourist preferences, seasonal and infrastructural constraints, logistical parameters, and the requirements of safe tasting tourism.

The developed multi-level model of intelligent routing, incorporating an input data module, an analytical–recommendation module, and an evaluation–feedback module, demonstrated practical viability during testing in six countries with different levels of digital maturity in their tourism ecosystems–Italy, France, Portugal, the United States, Russia, and Georgia. The test results confirm the high adaptability of the proposed model to varying destination conditions and reveal its potential for scaling to other wine-producing regions.

The empirical assessment identified a strong positive correlation between the level of digitalization of tourist destinations and tourist satisfaction with AI-generated routes (r = 0,92), as well as a moderate relationship between reduced planning time and increased profitability of wineries (r = 0,71). These findings confirm the pronounced economic effect of implementing intelligent routing systems and their significance for improving the quality of tourist routes.

Comparative analysis of traditional, agency, and AI-generated routes showed that intelligent routing provides a higher level of personalization, logistical optimality, and structural coherence of visit programs, while surpassing alternative approaches in key performance indicators (KPIs) – recommendation accuracy, evenness of tourist flow distribution, average spending, and winery return on investment.

Thus, the use of artificial intelligence in the organization of enotourism routes should be considered a promising tool for the sustainable development of wine-producing territories, for increasing their competitiveness, and for forming digital tourism ecosystems within the framework of smart tourism.

Future research prospects include expanding cross-country samples, advancing predictive modeling methods for tourist demand, deepening IoT integration in the management of enotourism infrastructure, and improving econometric models for evaluating the effectiveness of AI solutions. Additional attention is required for analyzing limitations associated with data heterogeneity and the variability of digital maturity across different regions.

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Material received 06.12.2025, approved 08.12.2025, accepted for publication 11.12.2025